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## Detection Of Premature Browning In Ground Beef with An Integrated Optical-Fibre Based Sensor Using Reflection Spectroscopy and Fibre Bragg Grating Technology

M. O'Farrell<sup>\*a</sup>, C. Sheridan<sup>a</sup>, E. Lewis<sup>a</sup>, W. Z. Zhao<sup>b</sup>, T. Sun<sup>b</sup>, K. T. V. Grattan<sup>b</sup>, J. Kerry<sup>b</sup>, N. Jackman<sup>b</sup>

<sup>a</sup>Department of Electronic & Computer Engineering, University of Limerick, Limerick, Ireland.

<sup>b</sup>School of Engineering & Mathematical Sciences, City University, Northampton Square, London

<sup>\*</sup>Echo Food Solutions International Ltd., Coolbanagher, Portlaoise, Co. Laois, Ireland  
marion.ofarrell@ul.ie

**Abstract.** This paper reports on an optical fibre based sensor system to detect the occurrence of premature browning in ground beef. Premature browning (PMB) occurs when, at a temperature below the pasteurisation temperature of 71°C, there are no traces of pink meat left in the patty. PMB is more frequent if poorer quality beef or beef that has been stored under imperfect conditions. The experimental work pertaining to this paper involved cooking fresh meat and meat that has been stored in a freezer for, 1 week, 1 month and 3 months and recording the reflected spectra and temperature at the core of the product, during the cooking process, in order to develop a classifier based on the spectral response and using a Self-Organising Map (SOM) to classify the patties into one of four categories, based on their colour. Further tests were also carried out on developing an all-optical fibre sensor for measuring both the temperature and colour in a single integrated probe. The integrated probe contains two different sensor concepts, one to monitor temperature, based on Fibre Bragg Grating (FBG) technology and a second for meat quality, based on reflection spectroscopy in the visible wavelength range.

### 1. Introduction

If ground beef is stored for long periods of time, above recommended temperatures, or is exposed to oxygen, oxidation can take place, causing the meat pigments to change to metmyoglobin. This pigment is darker in colour. Metmyoglobin can give the uncooked muscle a dark brown colour. During cooking, the beef pigment is altered by heat to become denatured myoglobin. If metmyoglobin is present in the muscle, the combination of the darker initial colour and the lack of heat stability of metmyoglobin mean that the beef can brown prematurely (a fully cooked appearance at a temperature less than 71°C, the temperature required to kill pathogens). This phenomenon is known as premature browning (PMB) and much work has been performed into proving the cause and occurrence of this [1-3]. It has been shown that beef cuts that were frozen for prolonged periods of time and then thawed and cooked demonstrate a higher likelihood of PMB [1]. The detection of PMB will require two

measurements, temperature and colour. Traditional methods for examining the colour of ground beef measure its CIE  $L^*a^*b^*$  or Hunter Lab values, which are obtained using a colorimeter [2,3]. For determining PMB the  $a^*$  value is the most significant value as it measures the redness of the sample; if used in conjunction with temperature, the measurement can be used as an indicator for PMB. Tristimulus readings are unsuitable for online measurement of PMB for several reasons. HunterLab states “the ideal sample for instrumental colour measurement would be completely opaque, uniform, flat, smooth, non-directional, homogeneous, and at least slightly larger than the instrument measurement port” [4]. A non-destructive, online measurement of the centre of a minced beef patty cannot meet these ideals. The structure of a minced product means that it won’t be uniform, flat or smooth and the presence of translucent substances such as fat and water mean that an opaque reading cannot be guaranteed. In addition, it is required that “when evaluating colour, the light should shine directly on the object from overhead and you should examine the specimen from a 45° angle (or vice versa)”. Therefore an alternative method of measuring the appearance of the food was utilised by measuring the reflection spectra of the meat using a slimline optical fibre probe and applying pattern recognition techniques to these spectra.

In conjunction with the experimental work for determining premature browning another investigation was conducted, which involved the design, fabrication and calibration of a novel and integrated probe that simultaneously measures colour and temperature. The sensor has considerable potential application in the areas of food quality monitoring with the aim to develop a new, compact, all-optical probe designed specifically for a range of oven systems, including microwave and/or hybrid ovens, that can simultaneously detect and analyse/correlate temperature and colour so that the combined sensor system can yield specific information regarding the quality of the meat and other food products being cooked

## 2. Methodology

Ground beef was purchased in five different retailers in Limerick City and labelled as A-E. 4 x 2lb portions of ground beef were purchased from each retailer. Each 2lb portion was made into 8 patties and stored as follows: 1) refrigerated until cooked the following day, 2) frozen for 1 week, 3) frozen 1 month and 4) frozen for 3 months. The frozen patties were thawed overnight in a fridge prior to cooking. The eight patties were divided into 4 patty groups, with 2 patties in each group. Each of the groups was cooked on a Teflon pan to one of four end-point temperatures: 57°C, 66°C, 71°C and 79°C. The reflectance spectra were measured at each of these endpoint temperatures at the core of the product. The patties were also visually assessed by two people and graded according to the *Kansas Agricultural Experiment Station Ground Beef Patty Cooked Color Guide* [5], which gives pictures of ground beef cooked to five temperatures between 65°C and 77°C. This guide displays a picture of the ideal colour of the patty at each temperature, a classification from medium rare to well-done and a description.

A K-type thermocouple with a USB 8-channel thermocouple DAQ system from Superlogics was initially used to measure and record the temperature. The patties were cooked for 2 minutes on each side, and then flipped at 1-minute intervals until the required temperature was reached. Changes in the spectra at each endpoint temperature were examined using an Ocean Optics S2000 spectrometer. The patties were illuminated using six fibres coupled to a tungsten halogen white light source that emits light in the 360nm to 2µm wavelength range and the reflected spectrum was returned to the spectrometer via a single fibre. After a patty had been cooked to a particular endpoint temperature, it was cut in half and spectra were recorded from the centre of each cross-section. This meant that for each group (consisting of 2 patties), up to four sets of spectra were recorded. During each spectral scan, 27 spectra were recorded and then averaged. In an online environment, the probe would be inserted into the centre of each patty without needing to cut the product in half.

To conduct the investigation into the possibility of an all-optical-fibre integrated probe for the purpose of measuring meat quality, one was designed to contain the colour monitoring reflection-based part (described above), which comprised 7 optical fibres each 200/220µm (6 illumination and 1

reflection) whereas the temperature sensing element was fabricated from one single-mode fibre, 125µm diameter with a single Fibre Bragg Grating at the tip. The integrated probe was designed therefore as a trifurcated bundle with three branches containing 1) 6 illumination fibres, 2) 1 reflection fibre and 3) a single mode fibre incorporating a FBG. Initially a ceramic sheath was considered as the outer tubing material in which to house the fibres, but due to the need to meet the industry-specified probe dimensions, this design was not sufficiently mechanically robust and therefore PEEK or Polyetheretherketone was chosen and used as an alternative. Stainless steel was not an option because it could not readily be used in a microwave environment. The final probe design that was developed in this work was manufactured by Ceramoptec GmbH and measured 50mm in length and 3mm in diameter. There were a few operational issues that needed to be addressed during calibration: The FBG fibre was surrounded by a polymer, which is an insulator with a low heat transfer rate, the FBG fibre was also fixed with an epoxy, which affects the strain on the fibre and therefore affects the FBG wavelength shift with changing temperature and finally there was also the possibility that FBG could experience uneven heating (even over the comparatively short active length) due to the presence of the reflection sensing fibres, which partially surround it.

Using the same K-type Thermocouple, the FBG temperature sensor was calibrated by placing the integrated probe and the thermocouple in a beaker of boiled water and allowed cool. Using this data the integrated probe was further tested in a microwave oven to verify its operation in the presence of microwaves

### 3. Results

#### 3.1. The Classifier

As stated above a visual assessment of the meat was also made by the authors at each endpoint temperature, using [8] as a reference. In this guide each grade has a corresponding temperature and description, Table 2(a). During the experiments for this paper, in general, it was found that patties cooked to 57°C were Medium Rare (Grade 1 or 2) and those cooked to 71°C or 79°C were Well-done (Grade 4 or 5). Patties cooked to 66°C should appear Medium Rare (Grade 1 or 2) but if premature browning is occurring, they could appear Medium or Well-done (Grade 3, 4 or 5). Focussing on this temperature, i.e. 66°C, Table 2(b), it can be seen that products A, B and D match the expected grading while Product E, which had been discounted and was approaching its best before date, was observed to be Grade 4, Medium-Well. Freezing the patties for one week had little impact on cooking grade while signs of PMB are present for all products after freezing for one month. These results are in agreement with previously reported results that show that freezing time has an impact on PMB [1].

Table 1. Grading of patties cooked to 66°C, assigned by the authors using [8].

(a)			(b)					
Grade	Temperature	Description	66°C	A	B	C	D	E
1	65C	Medium Rare	Fresh Samples	2	2	3	2	4
2	68C	↓	Frozen 1 week	2	2	3	2	4
3	71C	Medium	Frozen 1 month	3	3	4	3	5
4	74C	↓	Frozen 3 months	4	3	4	3	5
5	77C	Well-done						

By applying methods used previously by the authors [6] a training set with four classes of 256 spectra each was used to classify the data in this experiment – Medium Rare, Medium, Well Done and Dark. The average of the spectra in each class are given in Figure 1. Principal Component Analysis (PCA) as performed on the spectra to extract features in the data. The Principal Components (P.C.s) are shown in Figure. 1(b).

An SOM was trained to classify data using the training set. The results for the SOM are shown in Table 3. The grey cells indicate PMB samples. The general trend detected by the sensor matches that shown by the visual assessment in Table 2(b), i.e. the poorer quality meat, samples C and E show

more pronounced signs of PMB from the beginning and that the occurrence of premature browning increases with storage time. The increase in PMB with storage time is seen when summing the amount of PMB samples (grey cells) for each storage time, i.e. Fresh = 35 PMB samples, 1 Week = 39 PMB samples, 1 Month = 43 PMB samples and 3 Months = 51 PMB samples.

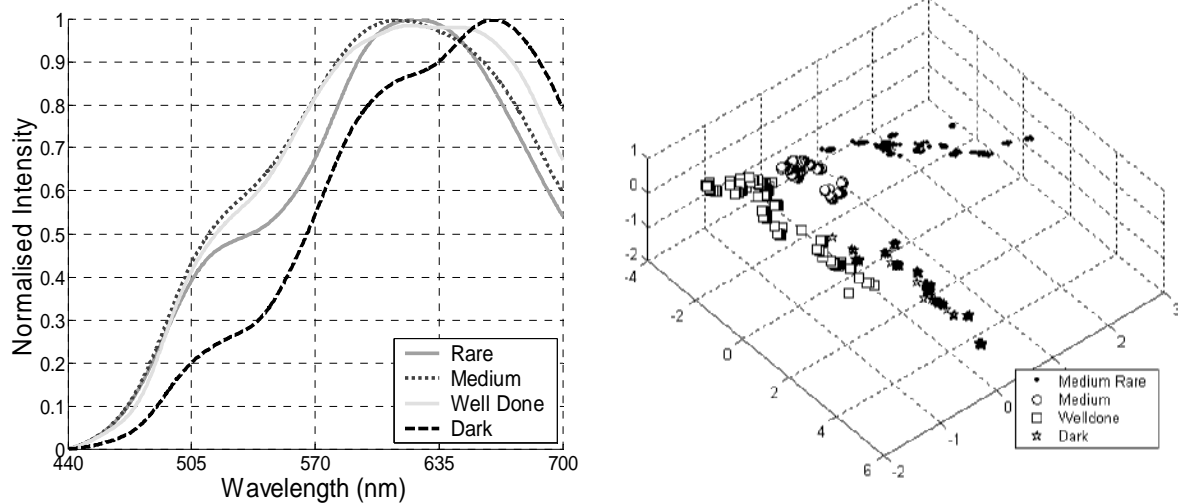


Figure. 1. (a) Shows the average spectra for each of the four training categories. (b) Shows the training data P.C.s

Table 2. Results for the SOM classifier. The grey cells indicate Premature Browning Samples

Classification	57C					66C					71C					79C				
<b>Fresh Samples</b>	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Medium Rare (Grade 1/2)	2	4	1	1		1	2		2							1				
Medium (Grade 3)			2	3	1	1		1			3	2		1						
Well Done (Grade 4/5)			1		3			3	1	4		2	4	3	4	2	4	4	4	4
Dark (Grade 5)						1	1	1												
Total Spectral Scans	2	4	4	4	4	2	4	4	4	4	3	4	4	4	4	3	4	4	4	4
<b>Frozen 1 week</b>	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Medium Rare (Grade 1/2)	3	3		4			1	1	2					2						
Medium (Grade 3)	1	1	3		3	1		1	2		1	1							3	
Well Done (Grade 4/5)			1		1	3	1	2		2	2	1	4	1	3	3	3	4	1	4
Dark (Grade 5)										2	1	2			1	1				
Total Spectral Scans	4	4	4	4	4	4	2	4	4	4	4	4	4	4	4	4	4	4	4	4
<b>Frozen 1 month</b>	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Medium Rare (Grade 1/2)	3	3		3		2	4		2											
Medium (Grade 3)	1								1		1	1		1		1				
Well Done (Grade 4/5)			4		4	1	1	4	1	3	2	4	4	3	4	3	3	3	3	4
Dark (Grade 5)						1				1	1	2			1	1				
Total Spectral Scans	4	3	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	4
<b>Frozen 3 months</b>	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Medium Rare (Grade 1/2)	4	2		2					1											
Medium (Grade 3)						1	2		1											
Well Done (Grade 4/5)		2	4	2	4	3	2	4	2	4	4	4	4	4	4	4	4	4	4	4
Dark (Grade 5)																				
Total Spectral Scans	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

### 3.2. The Integrated Probe Calibration

To calibrate the integrated probe it was placed in a beaker of boiled water with the k-type Thermocouple and allowed to cool. The temperature of the thermocouple was monitored against the shift in the FBG wavelength. The calibration was repeated 4 times and a plot of the temperature against wavelength is given in Figure 2.

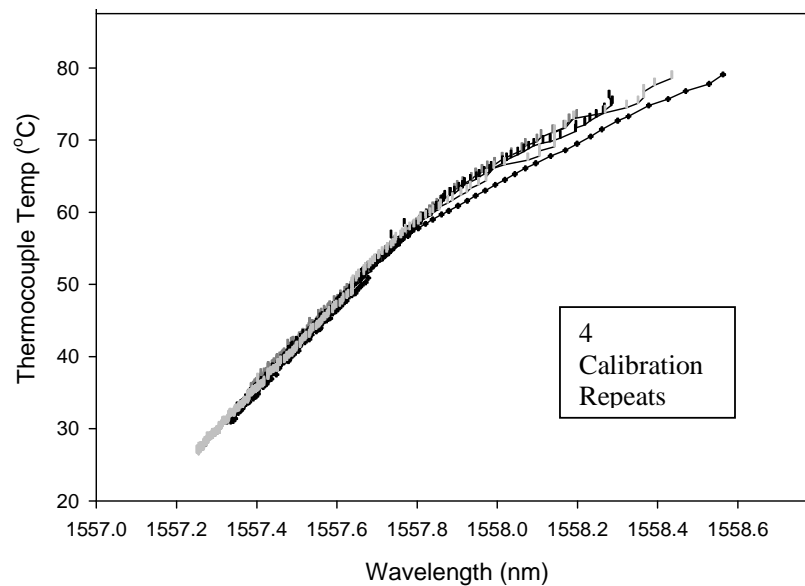


Figure 2: Wavelength shift in FBG with corresponding thermocouple temperature

The expected response for an FBG is that the wavelength shift is linear with temperature [7], however, it can be seen here that the integrated PEEK probe has a quadratic fit instead. This difference is attributed to the strain effects discussed above, arising from the structure of the probes and possibly from the thermal expansion in the epoxy in the PEEK probe that is exerting an increasing amount of strain with increasing temperature. To calibrate the sensor there was the option of performing a quadratic curve fit to the data using regression or generating a look-up table. The quadratic fit meant that you were limited to a temperature range but for the application it proved adequate because it has a narrow range of interest (typically food that is being cooked is monitored between 20°C and 90°C).

To test the suitability of this probe in a microwave environment, a standard microwave was drilled to allow insertion of the probe through the top and into the beaker Figure 3 (a). The water temperature was measured at time  $T=0$  with the thermocouple and the microwave was turned on for 3 minutes. This was repeated 3 times and both the wavelength shift and corresponding temperature calculated using the quadratic fit are shown in Figure 3 (b). As expected the sensor is indicating that temperature increases linearly with time in the microwave environment. At  $T = 180$  the microwave was turned off and the temperature of the water was measured using the thermocouple and in each case the initial and final temperatures measured by the thermocouple corresponded to the temperature reading from the optical fibre temperature sensor.

### 4. Conclusions

The work presented here demonstrates a method for detecting the presence of premature browning in ground beef using optical fibres in a slim-line non-destructive probe. An SOM classifier was tested

performed well in tracking the degree to which the meat has been cooked and detecting premature browning.

It has been further demonstrated that by modifying this probe by including a single mode fibre with and FBG that an integrated probe could be constructed to offer a complete solution to measuring food quality as it cooks. This probe was designed and constructed and in this paper it was demonstrated that it would be suitable for the food industry for use in both microwave and convection oven environments. The results demonstrate the need for careful design when integrating a reflection and temperature sensor element into a single probe, while simultaneously ensuring its suitability for use in the food industry.

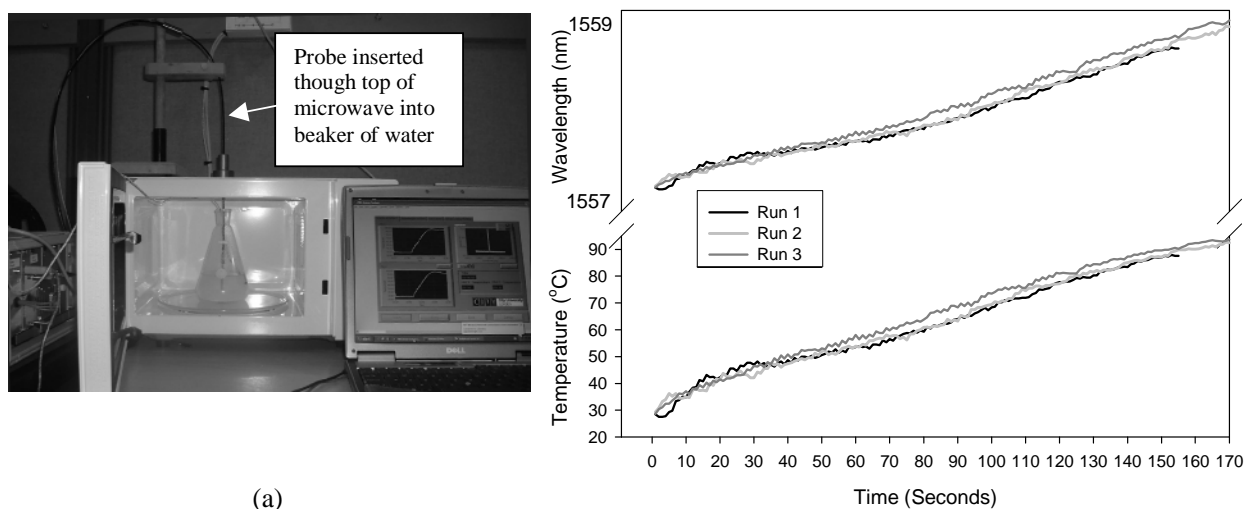


Figure 3: (a) Setup for testing senso in microwave environment (b) Wavelength and corresponding temperature progression with time spent in the microwave

## 5. References

- [1] S. M. Ryan, M. Seyfert, M. C. Hunt and R. A. Mancini, "Influence of cooking rate, endpoint temperature, post-cook hold time, and myoglobin redox state on internal color development of cooked ground beef patties", *Journal of Food Science*, 71, 216-221 (2006).
- [2] R. A. Mancini and M. C. Hunt, "Current research in meat color", *Meat Science*, 71, 100-121 (2005).
- [3] D. M. Wulf and J. W. Wise, "Measuring muscle color on beef carcasses using the L\*a\*b\* color space", *J. Anim. Sci.*, 77, 2418-2427 (1999).
- [4] Hunterlab Associates Inc., "Evaluation of Color", Applications Note Vol. 12, No. 6, (2000).
- [5] M. Hunt, "Ground Beef Patty Cooked Color Guide", Department of Animal Sciences and Industry, Weber Hall, KSU, Manhattan, KS 66506.
- [6] M. O'Farrell, E. Lewis, C. Flanagan, W.B. Lyons and N. Jackman, "Comparison of k-NN and neural network methods in the classification of spectral data from an optical fibre-based sensor system used for quality control in the food industry", *Sensors and Actuators B: Chemical*, 111-112, 354-362 (2005).
- [7] W. Z. Zhao T. Sun, K. T. V. Grattana, Y. H. Shen, C. L. Wei, and A. I. Al-Shamma'a, "Temperature monitoring of vehicle engine exhaust gases under vibration condition using optical fibre temperature sensor systems", *Journal of Physics: Conference Series* **45** (2006) 215-222